The reliability and validity of self-reported puffing behaviour: evidence from a cross-national study.

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Although self-reported puffing behaviour has considerable potential as an indicator of smoking intensity, particularly in survey research evaluating population-based changes in smoking patterns, little is known about its reliability and validity. This study compared smokers' perceptions of their puffing behaviour with measures of both machine-determined puffing behaviour and nicotine uptake to assess the utility of self-report. Self-reported puffing behaviour of 118 smokers from Australia, Canada, UK and US, as well as their demographic and smoking characteristics were assessed. At two visits, participants were asked to provide a saliva sample and to smoke a cigarette through a portable smoking topography device, the CReSSmicro, to measure puffing behaviour. Saliva samples were assayed for cotinine, a measure of nicotine uptake, to provide estimates of smoke exposure. Intra-class coefficients (ICCs) for all measures of self-reported general puffing behaviour were above 0.6 indicating that self-reported measures had fair-to-good test-retest reliability. Self-report, in particular inter-puff interval and number of cigarette puffs, was only moderately correlated with machine-determined puffing measures ($0.2<r<0.4$) and no self-report measure related to smoke exposure as measured by cotinine. Self-reported measures of puffing behaviour appear to be fairly reliable, but are only weakly correlated with objective measures of smoking topography. Results suggest that smokers have a better perception of the time spent between taking puffs and the number of puffs taken than the intensity and depth of each puff or their actual smoke exposure.

Introduction

Self-reported smoking status is a relatively good indicator of biomarker-validated smoking status (Patrick, Cheadle, Thompson, Diehr, Koepsell, & Kinne, 1994), with some notable exceptions (West, Zatonski, Przewozniak, & Jarvis, 2007). The fact that self-reported smoking status is a reliable proxy for biomarker-validated smoking status allows for the easy assessment of smoking prevalence in large nationally representative samples through standardized questionnaire items. However, smoking status and the number of cigarettes smoked per day are only crude indicators of tobacco consumption and intake. Puff topography studies show that there is significant variation among smokers in the way cigarettes are smoked (Hammond, Fong, Cummings, & Hyland, 2005). Some smokers inhale two to three times more smoke than others smoking the same number of cigarettes of the same brand by adjusting the number, size, and speed of their puffs to extract the desired amount of nicotine (Benowitz, 2001). As a result, smokers who switch to cigarettes with lower machine measured tar and nicotine yields can compensate for lower nicotine delivery by smoking the cigarettes more intensively to maintain a relatively constant level of nicotine in their body (Benowitz, Jacob, III, Kozlowski, & Yu, 1986; Bridges, Combs, Humble, Turbek, Rehm, & Haley, 1990; Djordjevic, Hoffmann, & Hoffmann, 1997).

The technology to measure such puffing behaviour has improved with the advent of portable, hand-held devices (Henningfield, Yingling, Griffiths, & Pickens, 1980). However, measuring puffing topography remains a relatively costly, involved procedure that may not be feasible for large population-based studies. If this information could be collected with sufficient accuracy via self-report, it would make studying puffing behaviour in population samples much easier. Yet, to date few studies have examined the extent to which smokers can provide accurate self-reports of their puffing behaviour. What research exists provides conflicting findings. For example, self-reported inhalation was found to be significantly associated with biological markers of smoke intake in some (Nakayama, Yokoyama, Yoshiike, Ichimura, Yamamoto, & Tanaka, 1999; Hofer, Nil, Wyss, & Battig, 1992; Burling, Lovett, Richter, &

Frederiksen, 1983), but not other studies (Frederiksen, Martin, & Webster, 1979; Hill, Haley, & Wynder, 1983; Etter & Perneger, 2001).

Validated measures of self-reported puffing behaviour would be particularly valuable for assessing individual variation in nicotine dependence, which could be useful in treatment planning, as well as for measuring compensatory shifts in response to tobacco control policies, such as increases in cigarette prices or taxation. For example, although tax/price increases have been demonstrated to reduce the number of cigarettes smoked (Jamrozik, 2004), it is not known whether smokers compensate by smoking each cigarette more intensely although there is good reason to believe that this is the case (e.g. see Ahijevych, Weed, & Clarke, 2004; Adda & Cornaglia, 2006). If each cigarette is smoked "harder", there may be little or no decrease in overall exposure resulting in a smaller than expected impact of taxation on health differentials. In addition, differences in puffing behaviour in terms of demographic or smoking characteristics may provide valuable insights into socio-demographic determinants of risk-exposure, smoking reduction and cessation as implied by recent studies reporting sex differences in machine-assessed puffing behaviour (Eissenberg, Adams, Riggins, III, & Likness, 1999; Wood, Wewers, Groner, & Ahijevych, 2004; Hammond et al., 2005).

As part of an international study assessing smokers' exposure to smoke carcinogens, we therefore sought to assess the value of self-reported puffing behaviour as a tool to estimate smoke intake. Self-reported puffing was compared with machine-determined smoking topography and a measure of nicotine uptake to examine its reliability and validity.

Methods

Participants

Study subjects included 118 adult daily smokers recruited in four countries: Australia (AUS), Canada (CA), United Kingdom (UK), and United States (US). Participants were recruited through advertisements in local newspapers, flyers, emails, or posters on public bulletin boards at five different sites: Waterloo, CA; Melbourne, AUS; London, UK; and Buffalo and Minneapolis, US. Smokers who responded to the advertisements were screened for eligibility by means of a telephone interview. Participants were included if they were between 18 and 50 years of age, had smoked at least ten cigarettes daily for the past year, and had been a regular smoker of one particular cigarette brand for more than 3 months. Seventeen eligible cigarette brands - between three and five brands from each country - were selected on the basis of national sales and nicotine yield. At least one of the most popular 'light' and 'regular' cigarette brands in each country were included. Smokers were ineligible if they had a history of lung or heart disease, or if they were pregnant. Participant characteristics are provided in Table 1. Ethical approval was sought and granted by local ethics committees at participating study sites.

Procedure

Participants visited the laboratory on two occasions, 24 hours apart, and were instructed to abstain from smoking at least half an hour before each visit in order to standardise conditions. At the first visit, participants were explained the purpose of the study and their written consent obtained. At both visits, participants were asked to provide information about their smoking behaviour before saliva and urine samples were collected. Between visits, participants were asked to continue smoking as usual and at the end of each session, participants smoked a cigarette through the CReSSmicro® machine (Plowshare Technologies, Inc. Baltimore, Maryland) to determine smoking topography. Participants were reimbursed the equivalent of $50 USD for their time.

Measures

Self-reported puffing behaviour

Four different self-report measures of smoking behaviour were assessed in a self-administered questionnaire. This included: 1) inter-puff interval, assessed by asking smokers how long on average they let the cigarette burn in between taking puffs; 2) number of puffs per cigarette, determined by asking smokers if they: (a) take a few puffs on each cigarette, (b) take more than a few puffs but not as many as they could or (c) take as many puffs as they can on each cigarette; 3) depth of inhalation, determined by a single multiple choice item. Smokers were asked if they: (a) don't inhale into the chest at all, (b) inhale only a little into the chest, (c) inhale deeply into the chest or (d) inhale into the chest as deeply as possible; 4) smoking intensity, assessed by asking smokers to indicate on a scale from 1 (not at all hard) to 10 (as hard as possible) how 'hard' they smoked cigarettes on average.

Machine-determined puffing behaviour

The CReSSmicro® machine is a battery-operated, hand-held portable device that measures a full complement of smoking topography variables including puff volume, puff count, puff duration, peak flow, inter-puff interval, time, and date. The device uses an orifice flow meter mouthpiece that produces a pressure drop related to the flow rate of smoke through the mouthpiece. Data are collected by having the participant insert a cigarette in the device and smoke the cigarette as normal. Once the participant is finished, the cigarette butt is withdrawn from the device and extinguished, as usual. Data are stored on the device until downloaded for analysis.

Marker of smoke exposure

Saliva samples were collected using a dental roll, which participants were asked to keep in the mouth until saturated. Samples were assayed for cotinine, a major metabolite of nicotine that provides a very sensitive and specific quantitative measurement of tobacco intake using a tandem mass spectrometric method (Bernert, Jr., McGuffey, Morrison, & Pirkle, 2000).

Demographic, smoking and cigarette characteristics

At the first visit, smokers were asked about their smoking history, quit attempts, future quit plans, as well as general demographic information. Questionnaire items were used to calculate the Heaviness of Smoking Index (HSI, Heatherton, Kozlowski, Frecker, Rickert, & Robinson, 1989), a short version of the Fagerström test for nicotine dependence. The HSI is derived from the time to the first cigarette (≤5 min=3 points; 6-30 min=2 points; 31-60 min=1 point; >60=0 points) and cigarettes per day (1-10=0 points; 11-20=1 point; 21-30=2 points; >30= 3 points) producing a scale from 0 to 6 with higher scores indicating greater dependence on nicotine.

Cigarette brands were characterized by standard ISO/FTC nicotine yields rather than brand name (e.g. Light/Mild/Regular, etc.) due to country differences that exist in terminology. Percent filter ventilation, an indicator of the degree of air dilution in cigarette smoke produced by the ventilation holes in cigarette filters, was measured with a KC-3 digital apparatus (Borgwaldt-KC, Richmond, VA, USA) following an established protocol (Kozlowski, Mehta, Sweeney, Schwartz, Vogler, Jarvis, & West, 1998).

Statistical Analysis

Statistical analysis was carried out using SPSS 14.0. Test-retest reliability was evaluated by computing intra-class correlation coefficients (ICC) using a two-way mixed model. Pearson product moment correlation coefficients or Spearman's rho coefficients (if the measures were non-parametric) were used to assess the degree of association between the various self-report measures with machine-determined measures of puffing behaviour. To assess if the results remained consistent across various subgroups, stratified analyses were performed controlling for demographic and smoking history variables. Group differences were assessed by means of Chi-square or Mann-Whitney U tests for dichotomous and ordinal data, and t-test or ANOVA for continuous variables. In addition, within-subject changes across visits were determined with paired t-tests and stepwise linear regression was conducted for multivariate analysis.

Results

Participant and country characteristics

A total of 157 smokers from four different countries participated in this study. Of these 17 were excluded because they violated the study protocol (participants failed to return for the follow-up appointment, had smoked different cigarettes or had shared their CReSS machine with others) and 22 because some or all of their data were lost or missing due to machine failure. There were no significant differences between excluded and included participants in any of the demographic or smoking characteristics except for quit attempts. Excluded participants were more likely to have attempted to quit smoking in the last 5 years than those included in the analysis (Fisher's Exact test, p=.02).

<Table 1 about here>

The 118 participants for whom we have complete data reported smoking a variety of eligible brands – the most popular brands in each country were: Marlboro Gold (61.5%, UK), Newport (38.9 %, USA), Players Light (61.6 %, Canada) and Peter Jackson Super Mild (40.0 %, Australia). Across sites, half of participants smoked cigarettes with machine-based nicotine yields of 1 mg or above while the other half smoked cigarettes with machine-based nicotine yields below 1 mg, as determined by standard ISO/FTC testing protocols; however, this differed by country ($\chi^2(3)=40.7$, $p<.001$). In Canada significantly fewer participants smoked lower nicotine yield cigarettes than in any other country, whereas in the UK all participants smoked lower nicotine yield cigarettes given regulatory limits in the EU. ANOVA indicated a small difference between countries in the heaviness of smoking among participants ($F(3,113)=3.3$; $p=.024$); yet, Tukey post-hoc analysis did not reveal significant disparities between specific countries and there were no other significant country-level differences for demographic or any additional smoking characteristics. As shown in Table 1, the average participant had been smoking for more than 14 years and currently smoked approximately 17 cigarettes per day. Just under half of participants had attempted to stop smoking in the last five years; however, the majority of participants had no plans to quit in the next 6 months.

Reliability Assessment

Test-retest reliability over a 24 hr interval for both self-report and puff topography measures are shown in Table 2. Intra-class coefficients (ICCs) for all measures of self-reported puffing behaviour and four of the six measures of the machine measured puff topography were above 0.6 indicating fair-to-good reliability. Thus self-reported puffing behaviour - notwithstanding natural variability in smoking topography - showed similar stability over time to machine-determined puffing behaviour in this sample. Since test-retest reliability was established and paired t-tests revealed no significant differences between visits on any self-report or CReSSmicro measure, further analyses were carried out using mean values across visits.

<Table 2 about here>

Validity Assessment

Table 3 shows the correlations among the four self-reported measures of cigarette puffing behaviours as well as among the six machine-determined measures of smoking topography, which tended in the anticipated direction thus underlining their reliability. As would be expected, among self-reported measures greater smoking intensity was associated with a larger number of cigarette puffs and a greater inhalation depth; the latter two measures were also positively correlated. In line with expectation, self-reported inter-puff interval was negatively correlated with the number of cigarette puffs, though this was not significant. In contrast, machine-determined puffs per cigarette were negatively correlated with machined-determined inter-puff interval as well as all other CReSSmicro parameters. Moreover, puff volume – being a function of peak and average puff flow as well as puff duration - was positively correlated with these measures and as anticipated a greater average puff flow was associated with a greater peak puff flow but a shorter puff duration by off-setting the need to puff for longer.

<Table 3 about here>

Self-reported measures of puffing behaviour were compared with machine-determined smoking topography to evaluate the content validity of self-report. Table 4 shows the association between self-report and machine measures indicating significant but weak correlations between some of these measures. This table includes two additional variables, which are composites of machine-determined puffing variables– total smoke volume (puff volume x puff number) and total puffing duration (puff duration x puff number). These were calculated in order to provide some measure of smoking behaviour at the cigarette level as opposed to puff level. Similarly, a compound measure of the self-report variables was computed by adding average self-reported puffs per cigarette, self-reported inhalation depth and the categorised and reversely coded self-reported inter-puff interval (6 categories; lower interval limits (in seconds): 0, 5, 10, 15, 20, 30) to obtain an equivalent overall measure of self-report with greater values indicating harder smoking of cigarettes. This measure was reliable (Cronbach's α=.88).

<Table 4 about here>

As might be expected, the two measures of the number of puffs per cigarette were positively correlated. When comparing categorical responses, smokers who reported taking more puffs per cigarette took a greater number of puffs as measured by the CReSSmicro device when compared to people that reported taking fewer puffs; however, this difference reached only near significance ($F(2,115)=2.8$, $p=.065$). The same applied to the total puffing duration per cigarette: smokers who reported taking more puffs per cigarette had a tendency to spend a longer time inhaling per cigarette ($F(2,115)=2.5$ $p=.084$).

Although there was a significant correlation between the self-reported and machine-determined inter-puff interval, smokers on average underestimated the time they spent between taking cigarette puffs in absolute terms by about 5.2 seconds. While roughly one third overestimated and two thirds underestimated the inter-puff interval, only twelve participants correctly reported the time they spent between taking puffs to within two seconds. This difference between actual and perceived inter-puff interval was significant ($t(117)=4.4$, $p<.001$). In addition, self-reporting a longer inter-puff interval was associated with a smaller total inhalation volume and a shorter inhalation duration per cigarette as recorded by the smoking topography device.

As can be seen in Table 4, the relationship between the measures of interpuff interval and puffs per cigarette was asymmetric. Whereas the self-reported inter-puff interval was negatively correlated with the machine-determined puffs per cigarette, the machine-determined inter-puff interval was not significantly correlated with the self-reported puffs per cigarette. Moreover, smokers' self-reported depth of inhalation was not significantly correlated to puff volume, inhalation volume per cigarette or any other CReSSmicro measures. Although self-reported smoking intensity was also not correlated to any machine measures, including average and peak puff flow as would be expected, it was significantly related to the total time that people spent with a cigarette (i.e. sum of both the puffing time and inter-puff interval; $r=.24$, $p=.009$, not shown). The compound self-report measure was significantly correlated with both the individual (though not the total) puff duration and the total smoke volume per cigarette suggesting some correspondence between overall machine-determined puffing behaviour and self-report.

Although the magnitude of some of the correlations between self-reported and machine-assessed puffing behaviours was reduced to non-significance when looking only at female smokers, low-tar as compared to high-tar cigarette smokers and smokers with a low as opposed to a high HSI score, none of these group differences in correlation coefficients were statistically significant. This finding was confirmed by further analysis. In order to systematically evaluate the possible influence of demographic or smoking characteristics, difference scores were calculated by subtracting self-report data from machine puffing data, either directly as for the inter-puff interval or using a z-score transformation to account for incompatibility in measurement scales. Stepwise multiple regression analysis predicting absolute values of these difference scores (i.e. the precision of smokers' estimates as compared to machine estimates) did not reveal any significant predictors.

In order to assess the construct validity of self-report and thus its utility, self-reported puffing behaviour was related to cotinine, a biomarker of nicotine uptake and smoke exposure. Valid cotinine results were obtained from 110 participants and average levels were comparable to population studies (mean=292 ng/ml; range: 55-622). None of the self-report measures was significantly associated with average cotinine levels in bivariate analysis and stepwise linear regression was conducted to estimate independent effects of self-report on cotinine. Controlling for age, sex, HIS, filter ventilation, as well as body mass index (to adjust for differences in metabolism) the results confirmed bivariate analysis: only greater heaviness of smoking (β=.43, t=5.3, $p<.001$) and age (β=.39, t=4.8, $p<.001$) but not self-reported puffing predicted cotinine levels. These results were not significantly changed when ISO nicotine yield was included in the prediction model or when looking at Visit 1 and 2 cotinine levels separately.

Discussion

This is the first multi-country study to investigate the reliability and validity of self-reported puffing behaviour. In agreement with previous research, machine-determined smoking topography indicates that people's puffing behaviour is relatively consistent for at least short periods (Lee, Malson, Waters, Moolchan, & Pickworth, 2003; Hammond et al., 2005) and this study was able to show that self-reports of general puffing behaviour were equally stable confirming results from an earlier study (Etter & Perneger, 2001).

Self-reported measures of puffing behaviour were by and large weakly correlated with machine-determined measures in the expected direction – a longer reported inter-puff interval was related to a longer machine measured inter-puff interval, although there was a difference in absolute terms. Similarly, a greater number of self-reported puffs per cigarette was associated with a greater number of machine measured cigarette puffs, while a greater self-reported smoking intensity was only related to a longer smoking duration and not a greater average or peak puff flow indicating that smokers' interpretation of intensity may be more strongly linked to temporal than physical factors such as speed of inhalation. Consistent with previous research (Tobin, Jenouri, & Sackner, 1982; Adams, Lee, Rawbone, & Guz, 1983), self-reported depth of inhalation was not correlated to either machine-determined inhalation at mouth level or cotinine. However, a composite of the self-report measures was significantly associated with the total puffing volume indicating that smokers had some general understanding of their overall smoking topography. This relationship between the machine and self-reported measures was not significantly influenced by any of the assessed demographic variables or smoking characteristics.

Self-reported puffing behaviour was also validated against a biomarker of nicotine intake to estimate the relationship between self-report and actual smoke exposure. The analysis of self-reported puffing behaviour and cotinine levels showed that the measures used in this study bear little, if any, relation to smoke intake. This differs from a previous report by Etter, which found self-reported smoking intensity to be a good predictor of cotinine levels (Etter & Perneger, 2001). There are a number of possible explanations for this discrepancy. It may be that the Etter measure of smoking intensity ("Indicate, on a scale from 0-100, the intensity of your smoking") was better than our measure at capturing puffing behaviour. Alternatively, the discrepancy may be due to differences in the samples; in the current study, participants were recruited at five sites in four different countries thus including smokers of a much broader and varied range of cigarettes. Lastly, differences in the methodology may have contributed to contradictory findings. In contrast to the previous study, in which one saliva sample was collected by mail, in the current investigation saliva samples were obtained in person on two occasions.

The weak association of self-report with machine-determined puffing behaviour, but not with a measure of smoke intake, salivary cotinine, will be the result of a number of intervening factors. The bodily uptake of smoke constituents is dependent not only on inhalation behaviour but also on smoke parameters such as mean particle size and smoker parameters such as lung morphology, vital capacity, rate of breathing and clearance of the lung (e.g. Darby, McNamee, & van Rossum, 1984). In addition, there is individual variability in the extent to which smokers metabolise nicotine, which may be partly contingent on genetic polymorphisms of the CYP2A6 gene (e.g. Nakajima, Kuroiwa, & Yokoi, 2002; Malaiyandi, Sellers, & Tyndale, 2005). The variability in cotinine values caused by these factors may explain why self-reported puffing behaviour was not related to cotinine although smokers can report with some validity their puffing behaviour.

This study has a number of limitations. The restricted relationship between the more objective measures and the self-report measures could reflect the inherent difficulty of the self-report task: smokers may have limited awareness of their discrete smoking behaviours, or it could be that the questions we asked to determine puffing behaviour, or the combination of these questions, was sub-optimal. Self-reported puffing was assessed with fairly crude questions that reflected “general” or “typical” puffing behaviour, while machine-determined puffing related to two particular cigarettes. However, the limited association between self-report and machine measures may also be due to problems with the latter measure. If the cigarettes were smoked in an atypical way with the device, this would reduce the utility of the machine measures as a gold standard for intake. Although a previous study using this device concluded that it provides a reliable and valid index of conventional smoking (Lee et al., 2003), some degree of reactivity cannot be excluded especially since participants only used the device for a total of two cigarettes. Given that smoking behaviour is known to be variable, this “snap-shot” measurement of smoking topography may therefore limit the conclusions that can be drawn based on machine measures alone.

This study also had a number of strengths. It was able to replicate findings across several countries in a controlled setting using comparable procedures. Not only does this lend a degree of generalisability to our results that could not be obtained from a single country study but also confirms the viability of this approach. Indeed, cross-national studies will arguably become ever more important for tobacco control as tobacco companies pursue increasingly globalised strategies and policies.

Overall, the modest concordance between self-reported and machine-determined smoking topography but not cotinine suggests that smokers have only limited self-awareness of their actual puffing behaviour and nicotine intake and more research is needed to see if questions with better sensitivity can be developed. In general, the results imply that smokers have a greater understanding of the number of puffs and the time in between puffs rather than of the depth, strength or intensity of each puff. It is currently unclear whether smokers’ self-perception of smoking topography is sensitive to changes in smoking behaviour over time – an area that requires further investigation. Given these restrictions, our findings suggest that self-reported puffing, as assessed in this study, has currently only limited utility for the evaluation of smoking topography and smoke exposure in international questionnaire studies (or surveys) of smoking behaviour.

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The authors of this manuscript have no conflicts of interest to declare.

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Tables

Table 1: Demographic and smoking characteristics

	Australia (N=20)		Canada (N=18)		UK (N=26)		USA (N=54)		**All Sites (N=118)**	
Demographic Characteristics										
Mean (SD) Age	33.6	(7.0)	29.0	(9.4)	31.0	(7.2)	31.3	(10.0)	**31.2**	**(8.9)**
Percent (N) Male	55.0	(11)	77.8	(14)	53.8	(14)	50.0	(27)	**55.9**	**(66)**
Smoking Characteristics										
Mean (SD) Cigarettes per day	18.6	(6.7)	15.1	(4.6)	15.9	(5.9)	17.5	(4.9)	**17.0**	**(5.5)**
Percent (N) Smokers of brands <1 mg nicotine	55.0	(11)	11.1	(2)	100.0	(26)	37.0	(20)	**50.0**	**(59)**
Mean (SD) Heaviness of smoking index	3.1	(1.2)	2.5	(1.4)	2.5	(1.1)	3.2	(1.1)	**2.9**	**(1.2)**
Mean (SD) Years of smoking	17.0	(8.2)	12.7	(9.1)	13.6	(7.4)	14.3	(10.1)	**14.3**	**(9.1)**
Percent (N) Quit attempt in last 5 years	40.0	(8)	50.0	(9)	50.0	(13)	33.3	(18)	**40.7**	**(48)**
Median (range) Length of quit attempt in days	31.5	(0-356)	60.0	(3-510)	60.0	(1-420)	60.0	(2-270)	**60.0**	**(0-510)**
Percent (N) Quit plans										
Next month	15.0	(3)	16.7	(3)	15.4	(4)	18.5	(10)	**16.9**	**(20)**
Next 6 months	25.0	(5)	22.2	(4)	34.6	(9)	22.2	(12)	**25.4**	**(30)**
Beyond 6 months	35.0	(7)	27.8	(5)	38.5	(10)	51.9	(28)	**42.4**	**(50)**
No quit plan	25.0	(5)	33.3	(6)	11.5	(3)	7.4	(4)	**15.3**	**(18)**

Table 2: Intra-class coefficients of puffing behaviour measures (N=118)

Self-report	**ICC (95% CI)**
Puffs per Cigarette	.628 (.505-.726)
Inter-puff Interval	.760 (.672-.827)
Inhalation Depth	.773 (.689-.837)
Smoking Intensity	.774 (.689-.837)
CReSSmicro device	
Puffs per Cigarette	.466 (.314-.596)
Inter-puff Interval	.498 (.350-.622)
Puff Volume	.701 (.597-.783)
Peak Puff Flow	.819 (.749-.870)
Average Puff Flow	.810 (.738-.864)
Puff Duration	.649 (.532-.743)

Table 3: Correlations within self-reported and within machine-determined measures of puffing behaviour

Self-report	Puffs per Cigarette§		Inter-puff Interval		Inhalation Depth§
Inter-puff Interval	-.063				
Inhalation Depth§	.185*		-.048		
Smoking Intensity	.375**		-.035		.625**
CReSSmicro device	**Puffs per Cigarette**	**Inter-puff Interval**	**Puff Volume**	**Peak Puff Flow**	**Average Puff Flow**
Inter-puff Interval	-.555**				
Puff Volume	-.416**	-.142			
Peak Puff Flow	-.181*	-.066	.567**		
Average Puff Flow	-.905**	-.057	.399**	.905**	
Puff Duration	-.327**	-.124	.654**	-.105	-.305**

* p<.05 level,**p<.01 level, § Spearman's rho (elsewhere Pearson's r)

Table 4: Correlations between self-reported and machine-determined puffing behaviour measures

		Self-report Measures				
		Puffs per Cigarette§	Inter-puff Interval#	Inhalation Depth§	Smoking Intensity#	Self-report Compound#
CReSSmicro Measures	Puffs per Cigarette	.240**	-.325**	.118	.032	.397**
	Inter-puff Interval	.015	.395**	.037	.145	-.370**
	Puff Volume	-.072	-.029	-.022	-.008	-.070
	Peak Puff Flow	-.077	.013	.007	.001	-.079
	Average Puff Flow	-.069	.008	.043	.063	-.060
	Puff Duration	.010	-.050	-.006	.064	.299**
	Total Puffing Duration (per cigarette)	.201*	-.283**	.043	.109	-.021
	Total Smoke Volume (per cigarette)	.170	-.290**	.065	.043	.282**

* p<.05 level,**p<.01 level; § Spearman's rho; # Pearson's r